STUDY ON NATURE BASED SEARCH ALGORITHMS FOR SOLVING OPTIMISATION PROBLEM WITH EMPHASIS ON APPLICATION TO ANTENNAS

Contents

1. Introduction to the subject 2
2. Objective(s) for the present work 3
3. Motivation for the present work 4
4. Description of the present research work 4
   4.1. Initial observations 4
   4.2. Approach for investigation 5
5. Conclusions of the research 7
6. Future research directions 7
7. Proposed contents of the thesis 8
8. List of publications 9
9. References 11

1. INTRODUCTION TO THE SUBJECT

This report is the synopsis of research work taken up on 'Study of Nature-Based Search Algorithms for solving optimization problems with emphasis on application to antennas'. Nature-based Search Algorithms (NBSA) broadly refer to the methodology of applying the adaptation philosophy found in nature for design of better systems. These algorithms are stochastic, gradient free and are largely independent of initial design/solution domain. These techniques are useful when dealing with multidimensional problems having large solution space and multiple objectives.

Some popular NBS Algorithms are Genetic Algorithms (GA), Particle Swarm Optimization (PSO) and Ant Colony Organization (ACO). GA is modeled after the Darwin's theory of evolution[1-4]. PSO[5-8] draws its inspiration from a group of birds flocking together and ACO[9-10] is based on the foraging behavior of ant colonies. All of them draw inspiration from Nature, and work on population sets of solutions.

The main objective of the present investigation is to provide a framework for solving complex optimization problems in the field of Electromagnetic Antenna Arrays (EAA). Optimization in the context of EAA generally refers to its design to meet certain requirements of radiation pattern, including its gain, beam width, side lobe level, shape etc. In certain specific systems, optimization would also involve meeting requirements in respect of size, weight, power consumption, heat dissipation, cost, complexity etc.

In case of systems involving very large number of antenna elements, an important aspect of the optimization involves 'thinning' of the array. Thinning refers to reducing total number of active elements in an antenna array without causing major degradation in system performance. The key factor in the design of thinned array is to optimally choose appropriate elements which can be electronically deactivated from the antenna head without significantly affecting the system performance. It is this problem which is studied in the present investigation.

From a mathematical perspective this is a nonlinear, multi-dimensional problem with multiple objectives and many constraints. Solution for such problem cannot be obtained by classical analytical techniques.

A cursory study shows that the size of the feasible solution space through which the search algorithm has to navigate and find solution would be extremely large due to the large number of antenna elements. Thus it is impossible to deploy brute force technique of exhaustive search. Essentially the search and optimization technique should aim at reducing the search time and computational resources.

In view of the above, present investigation has explored the possibility of using Nature Based Search Algorithms (NBSA) for solving the EAA thinning problem.

2. OBJECTIVE(S) FOR THE PRESENT WORK

Following are some of the objectives of the present work:

- Understand the implications of thinning in an antenna array and formulating it as an optimization problem.
- Study representative NBSA algorithms with a view of applying them for solving the thinning problem in antenna arrays.
- Comparing the suitability of the algorithms for this application and building a framework for the search strategy
- Identifying problems related to scaling and other issues related to thinning of large antenna arrays
- Investigating solutions for these problems and verifying the solutions through appropriate simulation studies.
- Examine suitability of NBSA approach for real-time dynamic thinning.
- Documentation so that further investigations can be carried out by other interested researchers.

3. MOTIVATION FOR THE PRESENT WORK

Motivation for the present work has come from the following aspects:

- Very limited work has been reported on thinning of large scale Electromagnetic Antenna Arrays.
- NBSA is an emerging field of study with enormous scope for application-oriented research.
- Proposed activity is an inter-disciplinary work involving Artificial Intelligence, biological systems and electronics and computational techniques; thus opportunities exist for learning and understanding new disciplines.
- Being an inter-disciplinary activity, scope exists for taking up exciting challenges.
- A project work taken up for DRDO to synthesize a thinned EAA with more than 4000 elements was also falling into the scope of the proposed research work. Promising results of this project work, its practical utility and relevance to national security have further augmented motivation of current research to a great extent.

4. DESCRIPTION OF THE PRESENT RESEARCH WORK

The following section discusses the Initial observations and the approach taken up for investigation.

4.1 INITIAL OBSERVATIONS

- Literature review indicates that the approach for optimum thinning in EAA has been attempted mostly on classical analytical lines.).[11-13]
- Very limited work involving NBSA for thinning of EAA has been done; most of the work is based on Genetic Algorithms (GA), Ant colony organization (ACO) and Particle swarming optimization PSO).[14-16]
- In spite of the many good features of these techniques, it has been reported that there is a need to ‘fine tune the parameters and customize the approach for each application’ individually. Also it has been observed that the ‘cost of determining the exact optimal

GA parameters usually exceeds the cost of solving the original problem'.

- Also NBSA techniques are fairly slow in converging to optimum solution especially when solution space is very large as in case of large EAA. Probably this is one reason why most of the reported research work in this area is restricted to small arrays of the order of few hundred elements only. Thus scaling is one of the major problems in applying NBSA to thinning in large EAA, involving thousands of antenna elements.
- In practical systems employing large EAA, there is often need to address issues related to externally changing scenario (Two typical examples in a radar system using a large EAA are the need for avoiding sudden unwanted disturbing signal and the need to switch antenna beam while tracking high speed multiple targets). Efficacy of thinning under such dynamic conditions is of importance which needs detailed investigation.
- The above aspects make the problem taken up for investigation both exciting and challenging.

4.2 APPROACH FOR INVESTIGATION

- Thinning in EAA can be formulated in two possible ways —
  (a)Shifting geometric locations of periodic antenna elements in an EAA and
  (b) Eliminating a subset of active elements in an EAA

The later was found to be more elegant for implementation through NBSA and was chosen for further study

- For preliminary establishment of the search strategy, a bench mark problem was chosen which lends itself for
  (a) Comparison of results with the work of previous researchers
  (b) Extendibility of the strategy for variations in EAA
  (c) Establishing robustness and versatility of the approach
- The benchmark problem involved optimizing a 100 element thinned linear array of isotropic radiators. The optimization was done based on SGA, ACO and PSO. Rationale for selecting the technique was also based on simplicity, ease of implementation, and adaptability. Results obtained were comparable with similar published results.
- In order to test the robustness, versatility and adaptability of the search strategy, the

approach was tested for

(a) Two extensions of the benchmark problem and

(b) Four different cases of EAA

- In all cases the strategy yielded desired results. In all cases no special efforts were done for fine tuning of parameters..
- Having established basic framework, the strategy was investigated for scaling to large

  EAA (involving thousands of antenna elements) and for adapting it to dynamic situations. Two implications were noticed

  (a) Need to navigate through large solution space

  (b) Need to cut down time for computation
- The following approaches were adapted to mitigate the above problem

  (a) Avoiding computational redundancy in calculations related to thinning process.

  (b) Exploiting symmetry to reduce the solution space through which the search needs to navigate and

  (c) Zoning to exploit a prior knowledge about EAA for cutting down overall time for optimization
- These aspects lead to the evolution of the search strategy which is termed in this investigation as '**T**hinning **A**lgorithm based on **G**enetic **S**earch' (TAGS) useful for a broad class of antenna arrays. Major features of TAGS are

  --- Search using Simple GA: This kept the approach simple and easily adaptable to any type of EAA

  --- Zoning based on Dynamic symmetry: This could exploit the symmetry found in certain biological systems (pineapple, sunflower, pinecones etc) for reducing computational overheads

  --- Cost based Objective function: Useful in case of unconventional array pattern requirements such as introducing a notch in radiation pattern, sudden electronic switching of antenna beam etc

  --- Concept of acceptable solution; Useful for dynamic thinning problems

--- Bulk Array Calculation (BAC): In comparison with the conventional approach, BAC gave a reduction in computations ranging from about 2.8 X 108 operations (in case of a simple 200 element linear array) to about 2.32X 10 12 operations(in case of a planar array of 4096 elements)

- Due to the non-availability of suitable platform for practical implementation, the approach was validated through software simulation. More than 5,000 cases of simulations of different types of EAA with various inputs and constraints were carried out. Representative results are given in chapter 5.
- Results were shared with experts in the field who were in a position to use the results for their design.
- In systems where direct implementation of thinning using TAGS is not feasible due to operational or other constraints, a concept based on a hard-wired 'Dynamic Thinning programmer' (DTP) has been proposed as part of the present investigations.

5. CONCLUSIONS OF THE RESEARCH

Based on the investigations carried out, following conclusions are drawn

- Nature based Search algorithms can be an effective tool in solving optimization problems related to Electromagnetic antenna Arrays (EAA).
- Thinning in large antenna arrays is a typical optimization problem which can be solved by using a framework based on Simple Genetic algorithm.
- Techniques such as Bulk Array Computation, Zoning, and concept of acceptable solution are useful in reducing overall computational time, in particular when optimization is attempted for dynamic conditions for large EAA.
- When operational requirements demand a much faster response time than is possible by real-time optimization using the above concept, a Dynamic Thinning Programmer can be used as a system integrator

6. FUTURE RESEARCH DIRECTIONS

- Concepts and results evolved out of the present investigations can be implemented on large working/ futuristic systems with large number of antenna elements (such as a Multi-function Phased array Radar with large Electronic scanning antenna system). This will help validating result of the present study, understand its implications and improve on the same.

- Scope exists for furthering research in which hybrid techniques can be employed for optimization.

7. PROPOSED CONTENTS OF THE THESIS

Thesis entitled "A study on Nature Based Search Algorithms for solving optimization problems with emphasis on application to antennas" is covered in six chapters. Figure 1 shows the document flow of the total investigative procedure.

Chapter 1 deals with the introduction to the subject and present investigation. It also summarizes objectives of the study. An extensive literature on thinning Electromagnetic Anrtenna Arrays(EAA) is covered in Chapter 2. Based on the conclusions made on the literature review, a hypothesis for the present investigative work is proposed in this chapter. It was proposed in view of this, the investigation was taken up in three phases.

Phase I: Technique for establishing Optimal Search Strategy

Phase II: Study on Scaling and Dynamic thinning

Phase III: Simulation Results and Discussions

The details of studies on these are covered in the next chapters.

In Chapter 3 an optimal search strategy using NBSA is established for array thinning problems. This is augmented with the simulated results presented for a benchmark problem involving few hundreds of antenna elements. Chapter 4 discusses the methodology for scaling up the above strategy for large practical systems involving few thousands of antenna elements. Search technique for exploring large solution space and implications of thinning for dynamic cases are also discussed here. In this connection zoning, geometric and dynamic symmetry, Bulk Array

Computation (BAC) and Thinning Algorithm based on Genetic Search (TAGS) have been evolved as a part of the present investigation.

Corresponding simulation results are presented in Chapter 5. Lastly Chapter 6 concludes with the summary of current research work and directions for future work.

Background information about EAA and related mathematical relationships are given in Annexure A. Annexure B lists the published work related to the present work.

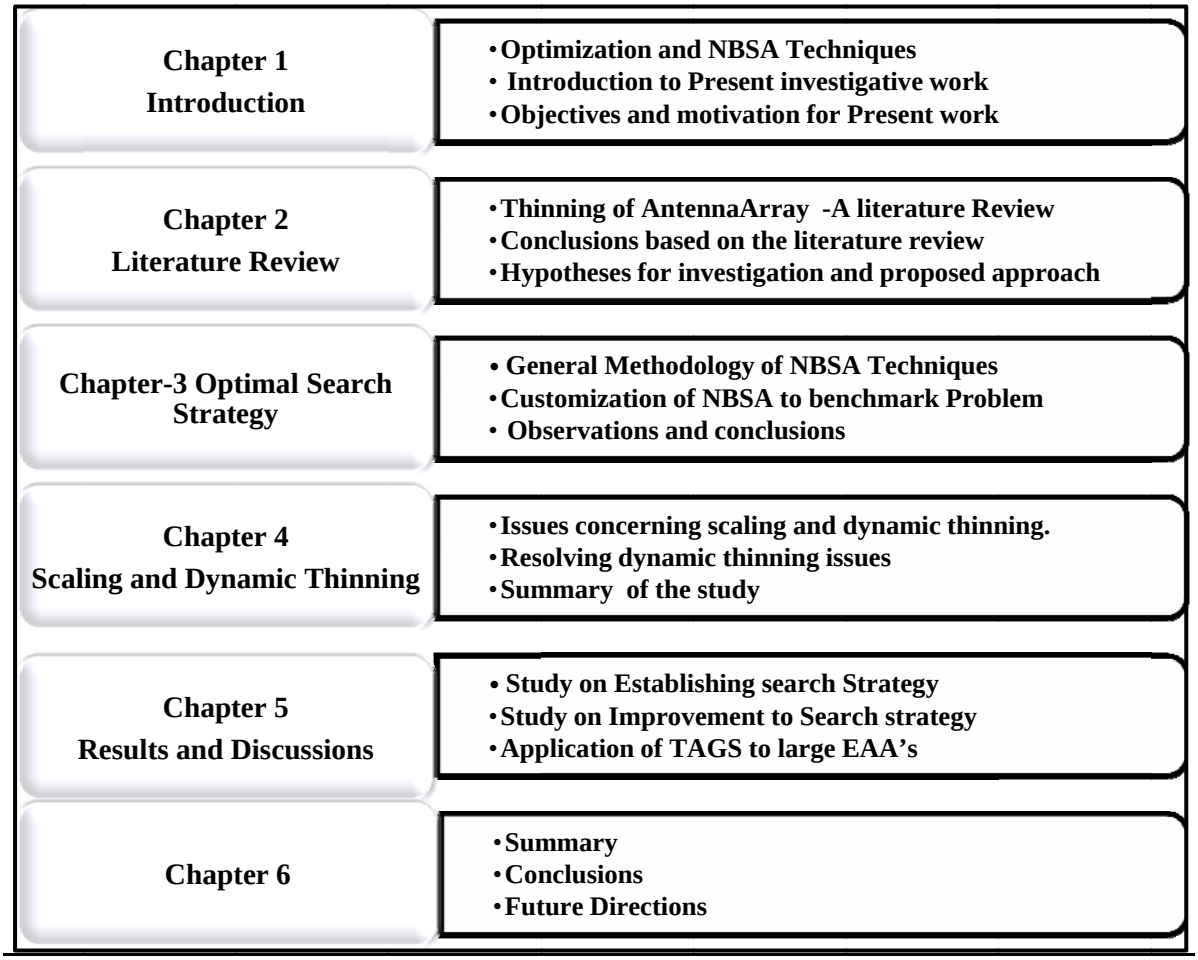

Figure 1: Thesis Organization

8. LIST OF PUBLICATIONS

JOURNAL PUBLICATIONS

1. R. Jain and G. S. Mani, "Dynamic thinning of antenna array using genetic algorithm," *Progress In Electromagnetic Research B*, Vol. 32, 1-20, 2011. 2009 **(Listed on Elsevier's Scopus)**
2. R Jain and G S Mani, Intelligent design of thinned Phased array – an approach", Journal of Operations Management, Vol. 3, No.1,Pg.No 192- 97, ISSN: 0976-7754, e-ISSN:0976-7762 (Indexcopernicus)

BOOK CHAPTER PUBLICATIONS

1. R.Jain and G S Mani, "Solving antenna array thinning problem using Genetic algorithm" *Genetic Algorithm / Book 3*, Intech Open access Publishers (In press)

INTERNATIONAL CONFERENCES / WORKSHOPS

2. Prof. Mani and Rajashree Jain, 'A study on using micro-GA techniques for thinning of antenna arrays', was accepted to be presented at 33rd IEEE Sarnoff Symposium, April 12-14, 2010, Nassau Inn, Princeton, NJ, US (could not attend)
3. Rajashree Jain and GS Mani, "Applying Micro GA concept for large and rugged solution space', IEEE TENCON2009, Singapore, 23-26 November, 2009 **(Listed on Elsevier's Scopus)**
4. Rajashree Jain, Jyoti Patole, "Synthesis of Antenna Arrays",Poster paper displayed and presented during The First IEEE Women in Electromagnetics Workshop (IEEE WIEM) June 5-8, 2009 at, Department of Electrical and Computer engineering, University of Utah, Salt Lake city, Utah, USA.
5. Rajashree Jain, Gaurang Kher, Chetan and Mani, "Synthesis of thinned antenna arrays using Bio-Inspired Algorithms", 4th International Conference on Radio Science ICRS-08, February 27-29, 2008, Jodhpur, India.

NATIONAL CONFERENCES

6. Jyoti Patole, Rajashree Jain and GS Mani, "Thinned Array optimization using ACO", to be presented during IEEE Women In Engineering Congress, 23 -24, October 2009, at Bengalure, India. (could not attend)

7. GSMani & Rajashree Jain "Exploring Genetic Algorithms for cost reduction of Radar antennas", ICAITE-08, Cummins college of Engg, Pune. (could not attend)

8. Rajashree Jain, Jyoti Patole, GS Mani, "AI tools for cost reduction of High Tech systems" National conference on Research Trends in Information Technology, NCRT-09, Dept. of IT, Sinhgad College of Engg., Pune, March 13-15, 2009.

TECHNICAL REPORTS (FOR RESTRICTED USE)

1. LRDE Technical report no STAR/JSCOE/2008-2, *Thinning of antenna arrays -- A Literature study,* December, 2008

2. LRDE Technical report no STAR/JSCOE/2009-1, *Using GA for thinning of linear antenna array,* January, 2009

3. LRDE Technical report no STAR/JSCOE/2009-3, *A study on array thinning using Ant Colony Optimization algorithm,* July, 2009

4. LRDE Technical report no STAR/JSCOE/2009-5, *Thinning of planar antenna arrays,* August, 2009

5. LRDE Technical report no STAR/JSCOE/2009-6, *Studies on thinning of 4096 element planar antenna array,* October, 2009

9. REFERENCES

[1] J. H. Holland, *Adaptation in natural and artificial systems*, Ann Arbor, University of Michigan Press,1975.

[2] D. E. Goldberg, *Genetic Algorithms in Search, Optimization, and Machine Learning*. New York: Addison Wesley Longman, 1989

[3] L. Davis, *Handbook of Genetic Algorithms*. Van Nostrand Reinhold, 1991

[4] K A De Jong, "An analysis of the behaviour of a class of genetic adaptive systems," Ph. D. dissertation, Univ. Michigan, 1975.

[5] J. Lis, "Parallel genetic algorithm with the dynamic control parameter," in Proc.3rd IEEE Conf. Evol.Comput.,1996, pp.324-329

[6] J. Kennedy and R. Eberhart, "Particle swarm optimization," in Proc. IEEE Int. Conf. Neural Networks, 1995, vol. 4, pp. 1942–1948.

[7] J. Kennedy and R. Eberhart, *Swarm Intelligence*, Morgan Kauffmann, San Fransisco,2001

[8] J. Robinson and Y. Rahmat-Samii, “Particle swarm optimization in electromagnetics,” IEEE Trans. Antennas Propag.,vol. 52, no. 2, pp.397–407, Feb.2004

[9] A. Colorni, M. Dorigo, and V. Maniezzo, ‘Distributed optimization by ant colonies’ Proceedings of ECAL'91, European Conference on Artificial Life, Elsevier Publishing, Amsterdam, 1991.

[10] Unz, “Linear arrays with arbitrarily distributed elements,” IRE Trans. on Antenna and Propagation, Vol. AP-8, pp 222-223, March 1960

[11] R. F. Harrington, “Sidelobe reduction by non-uniform element spacing,” IRE Trans.On Antenna ans Propagation, Vol. AP-9, pp 187-192, March 1961.

[12] M. Skolnik, J. Sherman, III, and F. Ogg, “Statistically designed density-tapered array,” IEEE Trans. Antennas Propag., vol. 12, no. 4, pp.408–417, Jul. 1964.

[13] M. Dorigo, V. Maniezzo, and A. Colorni, The ant system: an autocatalytic optimizing process, Technical Report TR91-016, Politecnico di Milano (1991).

[14] R L Haupt “Thinned Arrays using genetic algorithms,” IEEE Trans on Antennas and propagation, VOl 42, No 7, pp 993-999,July 1994.

[15] Majid M Khodier and Chrisotos, “Linear Array Geometry Synthesis With Minimum Sidelobe and Null Control using Particle Swarm Optimization”, IEEE Trans. Antennas and Propagation, Vol 53, No.8, pp 2674-21679, August 2005.

[16] E. Rajo-lglesias and O. Quevedo-Teruel, “Linear array synthesis using an ant-colony-optimization-based algorithm,” IEEE Antenna and Propagation Magazine, Vol. 49, Issue 2, April 2007, pp.70 – 79

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